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CDF

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B-physics results from the CDF Collaboration based on data collected during the Tevatron run 1A and 1B are presented. In particular we discuss the measurements of B meson masses and lifetimes, the limits set on rare B decay branching ratios and $B_0\bar{B}_0$ mixing results obtained with both time-integrated and time-evolution analysis. We use the current results to extrapolate CDF B-physics prospects to the end of run 1 and to the future high luminosity run II.

INTRODUCTION

The b production cross section is quite favourable at the Fermilab Tevatron, where proton and antiproton beams are collided with a center of mass energy of 1.8 TeV. A direct extrapolation from CDF data indicates a total cross section of $\sim 30 \mu\text{b}$ (1) in the region $|y| < 1$, where CDF has most of its muon and tracking coverage. For a typical run 1 luminosity of $\sim 10^{31} \text{ cm}^{-2}\cdot\text{sec}^{-1}$ this corresponds to a b production rate of $\sim 300 \text{ Hz}$. This is over an order of magnitude larger than the current CDF experiment data logging rate. On the other hand the backgrounds are also very significant; the ratio of the b cross section to the total inelastic cross section being in the order of 10^{-3} . This value of the signal to noise and the large production cross section imply that the quality of the trigger is of great importance to exploit at best the b-physics potential of the Tevatron. This is much different than the situation found at LEP at the Z_0 pole, where the cross section is smaller ($\sim 7 \text{ nb}$), but the signal to noise is much higher (~ 0.2).

Another characteristic feature of b-production at the Tevatron is that it is peaked at values of the b-quark p_t in the order of a few GeV/c, unlike at LEP where the b-quark momentum is about half the mass of the Z_0 . This puts additional constraints on the rejection power of the trigger and the analysis, since backgrounds tend to concentrate at lower p_t .

Rejection power at low p_t is achieved in CDF with two classes of triggers which require 1 or 2 leptons:

- a. dilepton triggers: either 2μ with $p_t > 2 \text{ GeV}/c$ or 1μ with $p_t > 2 \text{ GeV}/c$ and 1 electron with $E_t > 5 \text{ GeV}$

¹for the CDF Collaboration

- b. single lepton triggers: 1 electron with $E_t > 8 \text{ GeV}$ or 1 μ with $p_t > 7.5 \text{ GeV}/c$

Dimuon triggers are the main source of J/ψ , ψ' , which are used to select b-hadron exclusive decays. Dilepton triggers away from the J/ψ resonance are used for all $B_0\bar{B}_0$ mixing studies as well as for rare decay searches. Single lepton triggers are a source of semi-exclusive b-hadron semileptonic decays.

The CDF detector has been described in detail in (2). It is worth mentioning, however, some specific features of the detector which are of special relevance to b-physics. The muon system covers the pseudo-rapidity range $|\eta| < 1$. It consists of three separate subsystems:

- Central Muon Chambers (CMU) are located in the back of the central calorimeter modules and cover the region $|\eta| < 0.6$;
- Central Muon Upgrade (CMP) chambers are located behind the CMU after an additional 60 cm of steel to reduce the punchthrough background;
- Central Muon Extension (CMX) is a set of additional drift chambers and scintillation counters located in the region $0.6 < |\eta| < 1.0$.

Electron identification is done in the central and end-plug calorimeters in the region $|\eta| < 2.4$. Additional discrimination is achieved in the central region with the use of strip chambers located at approximately shower maximum inside the central electromagnetic calorimeters, with a preradiator located between the central calorimeters and the superconducting solenoid and with the use of dE/dx information from the Central Tracking Chamber(CTC). The tracking system is contained in a 3 m diameter superconducting solenoid providing a 1.4 Tesla axial field. Three tracking detectors are used:

- a. the CTC: a large volume drift chamber with 84 layers of sense wires, which provides most of the pattern recognition capability and momentum resolution.
- b. the Silicon Vertex Detector SVX (3): a 4 layer silicon microstrip vertex detector, which provides an excellent impact parameter resolution.
- c. the Vertex Time Projection Chambers (VTX): a set of small time projection chambers located between the CTC and the SVX, which provide R-z tracking in the vertex region.

The most relevant features of the combined tracking system are:

- high efficiency for tracks with $p_t > 0.4 \text{ GeV}/c$ and $|\eta| < 1$;
- good momentum resolution, $\Delta p_t/p_t^2 \sim 10^{-3} \text{ GeV}/c^{-1}$
- impact parameter resolution in the order of $13 \mu\text{m}$ for high momentum tracks.

Tracking with high resolution is important both to obtain a good signal to noise ratio in the reconstructed mass peaks and to achieve a good separation between the primary interaction vertex and secondary vertices from the decay of b-hadrons.

The CDF Collaboration has collected 20 pb^{-1} of data during run 1A and approximately an additional 50 pb^{-1} of data during run 1B, before the february '95 accelerator maintenance period. Most of the results reported in this paper refer to run 1A data, with a few mid-run updates. There are therefore significant improvements to be expected after the end of run 1B. In the rest of the paper we shall imply that the analysis refers to the run 1A data set unless a different data set is explicitly specified.

In the following we shall report the CDF results on the measurement of B meson masses and lifetimes, the limits set on rare B decays and the latest results on $B_0\bar{B}_0$ mixing. We shall then describe the improvements which are expected with the full run 1B statistics and discuss the b-physics reach of CDF for run II.

B MESON MASSES

The best resolution in the determination of the B meson masses can be achieved using their exclusive decays into J/ψ . The analysis starts with the selection of $J/\psi \rightarrow \mu^+\mu^-$ from the dimuon trigger data sample. A muon candidate is defined as a CTC track pointing to a track segment in the muon chambers. For each muon candidate we require that the position of the muon track segment in the muon chambers and the extrapolated CTC track match to within 3σ , where σ is the uncertainty in the extrapolation taking into account multiple scattering in the calorimeter material. Only three-dimensional CTC tracks are used, with the addition of the SVX information whenever it is available. We calculate the invariant mass of each opposite charge muon candidate pair after constraining them to originate from the same vertex. The J/ψ candidates are selected by requiring the difference between the dimuon mass and the world average J/ψ mass of $3096.9 \text{ MeV}/c^2$ (4) to be less than 3σ , where σ is the mass uncertainty calculated for each dimuon candidate. Approximately 80,000 J/ψ 's are found with less than 10% background in the peak region.

J/ψ candidates are then associated to additional tracks to select specific B decay modes. B masses and decay lengths are calculated after fitting all tracks to a common decay vertex with the constraints that the two μ have to form the J/ψ mass and the B candidate has to point to the primary vertex in the transverse plane. The χ^2 confidence level of this vertex fit is required to be greater than 1% for all decay modes. The following channels are used for the mass determination:

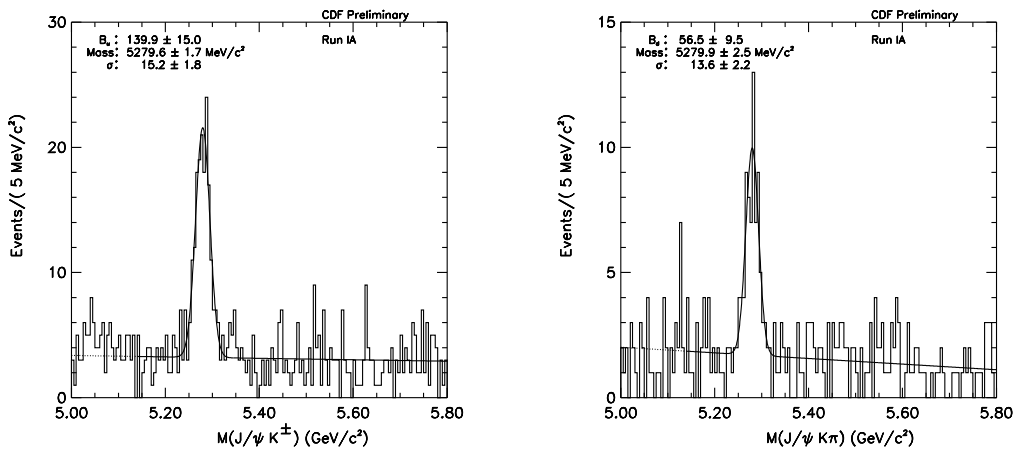
- i. $B_u^\pm \rightarrow J/\psi K^\pm$. The K^\pm is defined as any charged track and we assign it the kaon mass for the invariant mass determination. Additional cuts for this channel are: $p_t^{K^\pm} > 2 \text{ GeV}/c$, $p_t^B > 8 \text{ GeV}/c$ and $c\tau > 100$

TABLE 1. Summary of the CDF results on B meson masses.

B meson	CDF mass MeV/c ²	Compare to	
		Experiment	Value
B_u^\pm	$5279.6 \pm 1.7 \pm 2.9$	CLEO	5278.7 ± 2.0
B_d^0	$5279.9 \pm 2.5 \pm 3.7$	CLEO	5279.0 ± 2.0
B_s^0	$5367.7 \pm 2.4 \pm 4.8$	LEP avg.	5368.5 ± 5.3

μm , where $c\tau$ is the proper decay length of the B^\pm . In the left side plot of fig. 1 we show the resulting mass distribution.

- ii. $B_u^0 \rightarrow J/\psi K^{*0}(892)$. The K^{*0} is defined as any opposite charge two track combinations whose invariant mass is within $50 \text{ MeV}/c^2$ of the K^{*0} mass after assuming that one track is a charged kaon and the other is a charged pion. Additional cuts for this channel are $p_t^{K^{*0}} > 3 \text{ GeV}/c$, $p_t^B > 8 \text{ GeV}/c$ and $c\tau > 100 \mu\text{m}$. In the right side plot of fig. 1 we show the resulting mass distribution.

**FIG. 1.** $B^\pm \rightarrow J/\psi K^\pm$ (left) and $B^0 \rightarrow J/\psi K^{*0}$ (right) invariant mass distribution

- iii. $B_s^0 \rightarrow J/\psi \varphi$. The φ is defined as any opposite charge two track combination whose invariant mass is within $10 \text{ MeV}/c^2$ of the φ mass after assuming that both tracks are charged kaons. Additional cuts are $p_t^\varphi > 2 \text{ GeV}/c$, $p_t^B > 6 \text{ GeV}/c$ and $c\tau > 0$. In fig. 2 we show the resulting mass distribution.

In Table 1 we show a summary of these measurements compared to the latest CLEO and LEP results (5).

The CDF results are obtained after calibration of the p_t scale using the large sample of J/ψ 's available and correcting for dE/dx losses in the detector material. Systematic errors are dominated by instabilities in the events

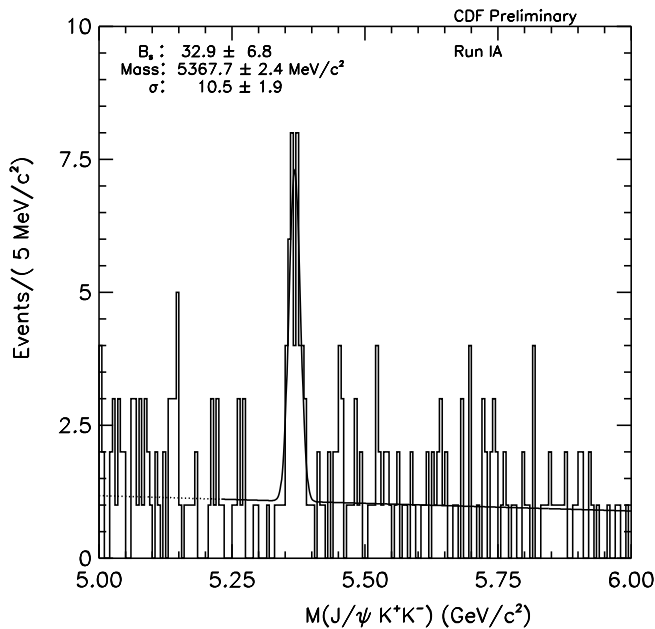


FIG. 2. $B_s^0 \rightarrow J/\psi \phi$ invariant mass distribution

selection and tracking systematics, besides residual scale uncertainties. A preliminary reanalysis of the data with an upgraded version of the tracking code shows good improvement of the stability of the results. We foresee that the systematic error will be lowered to a value $\sim 2 \text{ MeV}/c^2$ for all three B meson species.

B MESON LIFETIMES

The B meson lifetimes are sensitive to the details of the decay mechanism beyond the spectator model. Unlike the D^+/D^0 case, current B decay models predict very small differences between the B_u and the B_d lifetimes ($\sim 5\text{--}10\%$). Sensitivities of this order or smaller are therefore necessary in order to constrain the theory.

CDF reports a midrun update on the exclusive B_u and B_d lifetimes, which uses a total of 67.7 pb^{-1} of data and a new measurement of these lifetimes using semi-exclusive channels and run 1A data. The B_s lifetime has also been measured using the decay modes $B_s \rightarrow l \nu D_s$ and, with low statistics, $B_s \rightarrow J/\psi \phi$.

The transverse size of the beamline is small ($\sim 35 \mu$ in both the horizontal and vertical direction) at the B0 intersection point, where the CDF detector is located. For this reason we do not fit a primary event vertex in these analyses, but rather monitor the beamline position on a run-by-run basis and

use the average beamline position for the specific run as a measurement of the position of the primary vertex.

Exclusive $B_{u,d}$ lifetimes

The event selection for this analysis proceeds along lines quite similar to the B meson mass analysis, however more decay modes are used, no $c\tau$ cut is applied and no vertex pointing constraint is applied in the vertex fit to avoid biasing the $c\tau$ distribution. All the kinematical cuts have been reoptimized to obtain the best lifetime resolution. The B decay modes used for this analysis are: $B \rightarrow \Psi K$, where Ψ is either a J/ψ or a $\psi(2S)$ and K can be any of the following: K^\pm , $K^{*0} \rightarrow K\pi$, $K_S^0 \rightarrow \pi^+\pi^-$ or $K^{*+} \rightarrow K_S^0\pi^+$. In addition both muons are required to have SVX information, in order to guarantee an adequate secondary vertex resolution. A total of approximately 140,000 J/ψ 's is used.

We define the transverse decay distance, L_{xy} , of the B meson as the vector difference of the secondary and primary vertex positions in the transverse plane projected onto the B transverse momentum vector, \vec{p}_t :

$$L_{xy} = \frac{(\vec{x}_{sec} - \vec{x}_{prim}) \cdot \vec{p}_t^B}{p_t^B}$$

From L_{xy} we extract the proper lifepath, $c\tau$, by correcting for the appropriate $\beta_t\gamma$ factor:

$$c\tau = L_{xy} \frac{M_B}{p_t^B}$$

where M_B is the mass of the B meson and p_t^B its transverse momentum.

With these definitions we can make the proper decay time distribution for charged and neutral B 's. The signal region is defined by those B candidates whose mass difference, $|\Delta M|$, with respect to the world average B mass is less than $30 \text{ MeV}/c^2$. Similarly a sideband region is defined by the condition $60 \text{ MeV}/c^2 < |\Delta M| < 120 \text{ MeV}/c^2$. The $c\tau$ distributions for charged and neutral B 's in the two mass regions are shown in fig. 3.

The shape of the background is determined by fitting the sideband region to a gaussian with exponential tails. The shape of the signal region is assumed to be a weighed sum of the sideband shape and an exponential convoluted with a gaussian. The relative weights are constrained by the average amount of background measured in the mass plots for the signal region. After applying an unbinned fit to account for the event by event variation of the L_{xy} resolution we obtain the results shown in Table 2. Fit results are also shown in fig. 3 overlaid on the $c\tau$ distributions.

The systematic errors depend mostly on residual misalignments, trigger bias and beam stability. Since they affect equally the charged and neutral B , they are assumed to cancel in the lifetime ratio.

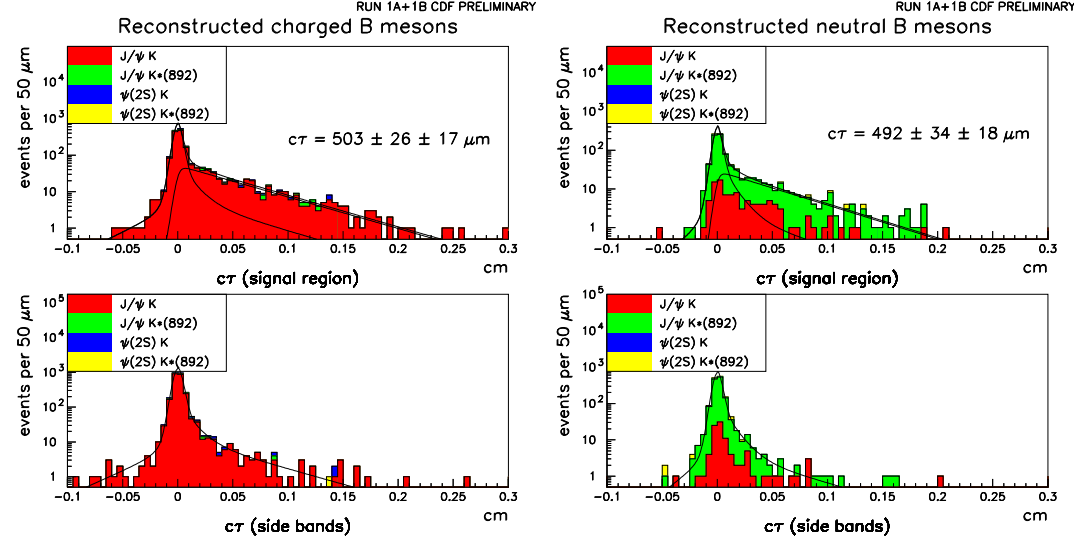


FIG. 3. Signal and sideband $c\tau$ distributions for B^+ (left) and B^0 (right)

TABLE 2. B_u^+ , B_d^0 lifetimes and their ratio

$\tau(B_u^+)$ psec.	$\tau(B_d^0)$ psec.	τ^+/τ^0
$1.68 \pm 0.09 \pm 0.06$	$1.64 \pm 0.11 \pm 0.06$	$1.02 \pm 0.09 \pm 0.01$

Semi-exclusive $B_{u,d}$ lifetimes

Another approach to measuring $B_{u,d}$ lifetimes is to use B semileptonic decays. From a large sample of inclusive single lepton triggers we search for D mesons in a cone around the trigger electron or muon. The D channels selected are:

- $D^0 \rightarrow K^- \pi^+$
- $D^{*+} \rightarrow D^0 \pi_s^+, D^0 \rightarrow K^- \pi^+$
- $D^{*+} \rightarrow D^0 \pi_s^+, D^0 \rightarrow K^- \pi^+ X$
- $D^{*+} \rightarrow D^0 \pi_s^+, D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$

where the channel c. is dominated by $D^0 \rightarrow K^- \rho^+$ decays where the π^0 is lost. A well defined correlation between the sign of the lepton and that of the kaon is present if the lepton and the D originate from the decay of a

B meson. Indeed, no signal is observed in the "wrong sign" combinations, while very clean D peaks are seen for the invariant mass of the "right sign" combinations, as shown in fig. 4 and 5

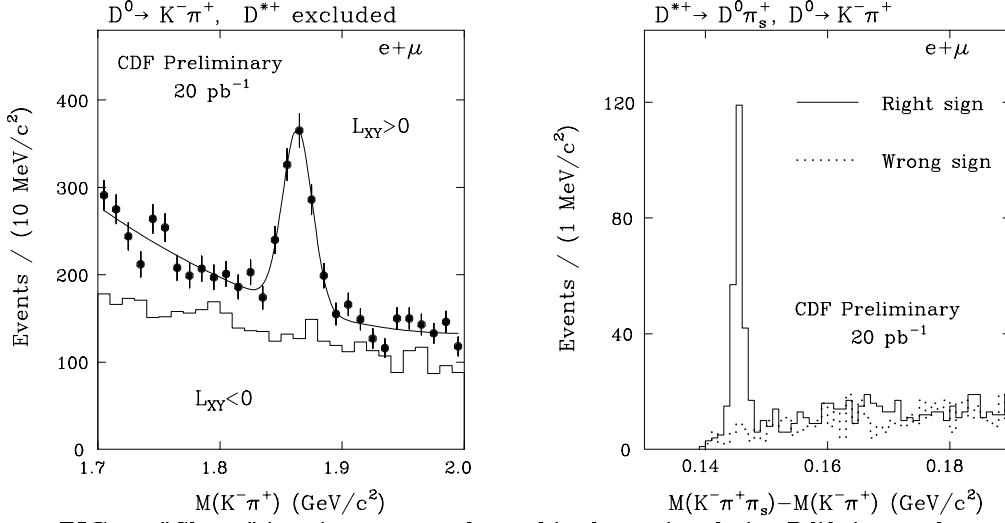


FIG. 4. "Charm" invariant mass peaks used in the semi-exclusive B lifetime analysis. Left: $D^0 \rightarrow K^-\pi^+$, right: $D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+$

In analogy with the exclusive measurement we define a secondary vertex, as the intersection of the D and lepton trajectories in the plane transverse to the beam axis, and a transverse decay length, L_{xy} , as the projection of the vector difference of the secondary and primary vertex transverse positions onto the direction of the Dl system. In this case it is not possible to calculate the $\beta_t\gamma$ factor exactly, since we are missing a neutrino, $c\tau$ is therefore defined as follows:

$$c\tau = L_{xy} \cdot \frac{M_B}{p_t^{Dl}} \cdot K$$

where K is an average correction calculated with the Montecarlo.

If we exclude from the sample a. the D^0 's which are associated to a soft pion to form a $D^{*\pm}$ we are left with 2 almost orthogonal samples: a lepton D^0 sample, which comes mostly from charged B decays, and a lepton $D^{*\pm}$ sample which comes mostly from neutral B decays. In practice there is some cross talk between the two samples due to B decays to $D^{*0}l\nu$ and to some inefficiency in the association of the π to the D^0 to form a $D^{*\pm}$. The relative amount of B^\pm and B^0 present in all samples is modeled with the Montecarlo and taken into account in a global fit to all samples, which is used to determine the separate charged and neutral B lifetimes. Uncertainties in the modeling of the sample composition are found to have very little effect on the observed lifetime. The final results of this analysis are shown in Table 3.

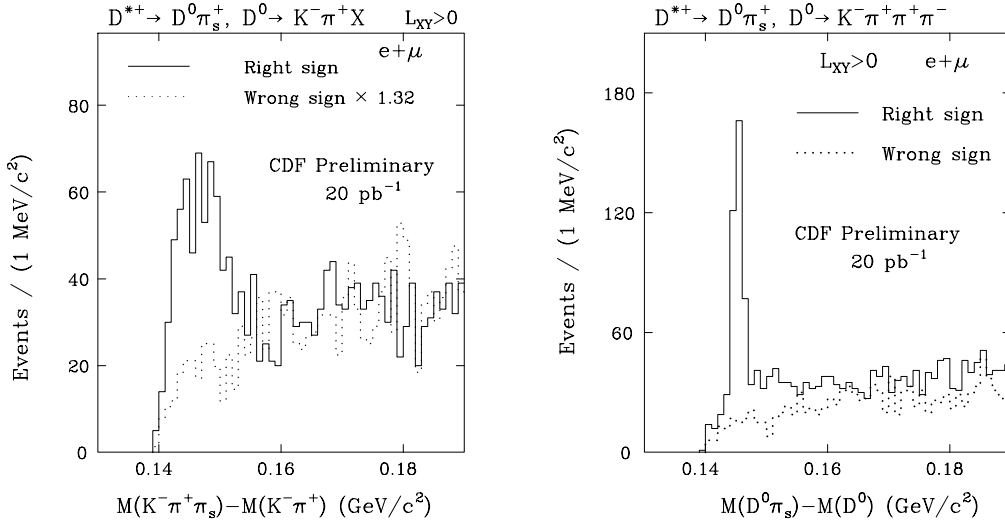


FIG. 5. "Charm" invariant mass peaks used in the semi-exclusive B lifetime analysis. Left: $D^{*+} \rightarrow D^0 \pi^+$, $D^0 \rightarrow K^- \pi^+ X$, right: $D^{*+} \rightarrow D^0 \pi^+$, $D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$

TABLE 3. B_u^+ , B_d^0 lifetimes and their ratio

$\tau(B_u^+)$ psec.	$\tau(B_d^0)$ psec.	τ^+ / τ^0
$1.51 \pm 0.12 \pm 0.08$	$1.57 \pm 0.08 \pm 0.07$	$0.96 \pm 0.10 \pm 0.05$

These results as well as the exclusive analysis ones are both consistent and competitive with the values obtained by the LEP experiments. In Fig. 6 we show a comparison of the CDF measurement of the charged to neutral $B_{u,d}$ lifetime ratio and the current measurements at LEP.

B_s lifetime

The lifetime of the B_s meson has been measured (6) using both the exclusive decay to $J/\psi \varphi$ and the semi-exclusive decay to $D_s l \nu$, $D_s \rightarrow \varphi \pi$, using analysis techniques quite similar to those described in the previous sections. In the first case the statistics is very low (just 8 events after background subtraction) and the result has a very large statistical error: $\tau_{B_s} = 1.74_{-0.69}^{+1.08} \pm 0.07$ psec. In the second case about 76 "right sign" D_s are found and a more accurate measurement is feasible: $\tau_{B_s} = 1.42_{-0.23}^{+0.27} \pm 0.11$ psec. Even this measurement is clearly still statistics limited and we expect much improvement after adding the run 1B data.

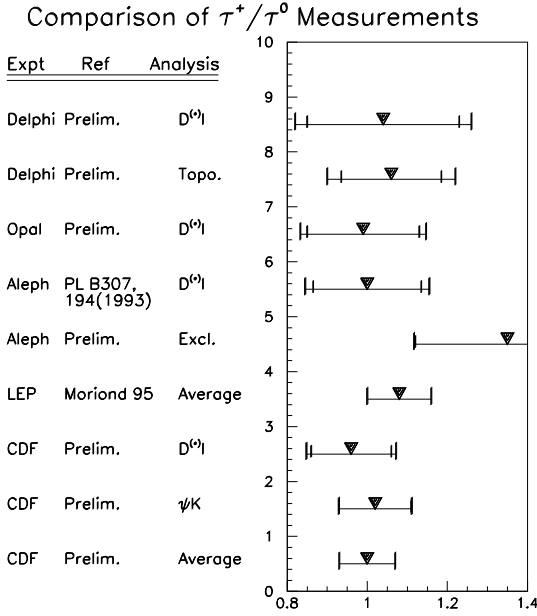


FIG. 6. World B^+ / B^0 lifetime ratios as of March '95

RARE B DECAYS

The availability of a large b cross section and highly efficient dimuon triggers puts CDF in a rather unique situation for the measurement of rare B decays with 2 muons in the final state. We present limits on the branching ratios of the decays: $B \rightarrow \mu\mu K$, where the K is either a K^\pm or a K^* and the $\mu\mu$ pair is away from the J/ψ and ψ' resonant regions, and $B \rightarrow \mu\mu$. These decays can occur, within the Standard Model, only via higher order loops containing quarks and vector bosons and are therefore strongly suppressed. Any anomalously large value for these branching ratios would be an indication of new physics.

For the $\mu\mu K$ decays the analysis runs in parallel for the resonant and non-resonant components. This way the non-resonant branching fraction can be expressed as a function of the known branching ratio of the process $B \rightarrow J/\psi K$, the ratios of the efficiencies and the ratio of the number of observed events for each component. This procedure reduces considerably the uncertainties in the measurement. Due to the trigger selection, only about one third of the available non-resonant $\mu\mu$ invariant mass spectrum can be measured and a calculation based on theoretical models (7) is necessary to extrapolate to the whole spectrum. No signal is observed above background. The 90% confidence level limit is shown in Table. 4 and compared to recent CLEO limits (8) and Standard Model predictions (9).

For the $B \rightarrow \mu\mu$ analysis we count the number of observed muon pairs

TABLE 4. 90% C.L. limits for the non-resonant $B \rightarrow \mu\mu K^\pm$ and $B \rightarrow \mu\mu K^*$ branching ratios compared to Standard Model predictions

	$\text{BR}(\mu\mu K^\pm)$	$\text{BR}(\mu\mu K^*)$
CDF	3.5×10^{-5}	5.1×10^{-5}
CLEO	0.9×10^{-5}	3.1×10^{-5}
S.M.	4.4×10^{-7}	2.3×10^{-6}

TABLE 5. 90% C.L. limits for the $B_d^0 \rightarrow \mu\mu$ and $B_s^0 \rightarrow \mu\mu$ branching ratios compared to Standard Model predictions

	$\text{BR}(B_d^0 \rightarrow \mu\mu)$	$\text{BR}(B_s^0 \rightarrow \mu\mu)$
CDF	1.6×10^{-6}	8.4×10^{-6}
CLEO	5.9×10^{-6}	
S.M.	8.0×10^{-11}	1.8×10^{-9}

with invariant mass in the B_d^0 and B_s^0 mass region. We apply vertex displacement and isolation cuts, which enhance the B component relative to the background. Given the large sample of J/ψ available, the efficiency of the cuts can be estimated mostly from the data with good accuracy. After normalizing to the measured B cross section (1) for $p_t^B > 6$ GeV/c with the assumption that the cross section for B_u or B_d is 3 times that of B_s , we obtain the 90% confidence level limits shown in Table 5. Here we compare our results to a recent CLEO measurement (10) and Standard Model predictions (11).

$B_0\bar{B}_0$ MIXING

$B^0 \rightarrow \bar{B}^0$ transitions are allowed by the Standard Model via higher order weak interaction contributions. This leads to the existence of non-diagonal terms in the mass matrix of the $B^0\bar{B}^0$ system. We shall define $x = \Delta m/\Gamma$, where Δm is the mass difference and Γ the average width of the eigenstates of this mass matrix. Another consequence of these transitions is that a B^0 produced at time $t = 0$ has a certain probability to turn (mix) into a \bar{B}^0 at time t according to the formula:

$$\mathcal{P}(B^0(0) \rightarrow \bar{B}^0(t)) = \frac{e^{-t/\tau}}{2\tau} \cdot (1 - \cos(\Delta mt)) \quad (1)$$

where τ is the B meson lifetime. We can integrate the above formula to obtain the overall probability that an originally produced B^0 mixes to a \bar{B}^0 :

$$\mathcal{P}(B^0 \rightarrow \bar{B}^0) = \chi = \frac{x^2}{2(1+x^2)} \quad (2)$$

The mixing parameters $x_{d,s}$, for the $B_{d,s}^0$ mesons, are tightly related to the elements $V_{t(d,s)}$ of the CKM matrix.

Experimentally the direct measurement of the mixing parameters $x_{d,s}$ is quite challenging. For this reason the first available measurements have been those of the related parameter χ . However only e^+e^- experiments running on the $\Upsilon(4S)$ can make a pure measurement of χ_d , since there are no contributions from B_s . At the Tevatron and LEP, where B_s 's are also produced, one in general measures an average $\bar{\chi} = F_d\chi_d + F_s\chi_s$, where F_d and F_s are the average fractions of B_d and B_s produced. Moreover, for large values of x , χ saturates to the value 0.5 as shown by eq. 2. This limits the sensitivity of this technique on x_s , which is expected to be large. At lot of effort has therefore gone into studying the time-evolution of the mixing oscillation, which provides a direct measurement of x , and results are now available from LEP and CDF.

CDF time-integrated measurements

CDF has updated its old time-integrated measurement (12) with 2 new results: one using $e\mu$ triggers and the other using $\mu\mu$ triggers. Both analyses exploit the charge correlation between the b -quark type and the sign of the lepton; indeed $b \rightarrow l^- + c$ while $\bar{b} \rightarrow l^+ + \bar{c}$. Since b -quarks are produced as $b\bar{b}$ pairs, for a pure b sample and ignoring sequential semi-leptonic decays $b \rightarrow c \rightarrow l^+$ the ratio, R , of the number of events with like-sign leptons (LS) to the number of events with opposite-sign leptons (OS) is given by:

$$R = \frac{LS}{OS} = \frac{2\bar{\chi}(1-\bar{\chi})}{\bar{\chi}^2 + (1-\bar{\chi})^2} \quad (3)$$

In practice this ideal situation is complicated by the presence of sequential $b \rightarrow c \rightarrow l^+$ decays, and several backgrounds, mostly fake leptons or in-flight decays of kaons and pions and semi-leptonic decays of direct charm. For the $e\mu$ analysis strict lepton identification cuts and a cut on the p_t of the lepton relative to the average direction of the nearby tracks (p_t^{rel}) are applied to reduce these contributions. They have however to be taken into account when relating R to $\bar{\chi}$; equation 3 becomes then:

$$R = \left(\frac{LS}{OS} \right)_{exp} \frac{1 - F_{e\mu}(LS)}{1 - F_{e\mu}(OS)} = \left(\frac{2\bar{\chi}(1-\bar{\chi}) + [\bar{\chi}^2 + (1-\bar{\chi})^2]f_s}{\bar{\chi}^2 + (1-\bar{\chi})^2 + 2\bar{\chi}(1-\bar{\chi})f_s + f_c} \right) \quad (4)$$

where:

- $f_s = \#(b \rightarrow c \rightarrow l) / \#(b \rightarrow l)$ is the ratio of sequential to direct decays. With a tuned Montecarlo simulation we estimate: $f_s = 0.186 \pm 0.034$.
- $f_c = \#(c\bar{c}) / \#(b\bar{b})$ is the ratio of charm to beauty production passing the analysis cuts. Due to uncertainties in the theoretical cross sections, this ratio is estimated directly from the data by fitting the p_t^{rel} distribution of the leptons to shapes determined with the Montecarlo. We obtain the value: $f_c = 0.041 \pm 0.014$.

- $F_{e\mu}(LS)$ and $F_{e\mu}(OS)$ are the fractions of fake and decay-in-flight leptons in the like-sign and opposite-sign samples. These quantities are estimated by releasing the lepton identification cuts and then determining the cut efficiencies using appropriate control samples and Montecarlo simulations. The results are: $F_{e\mu}(LS) = 0.365 \pm 0.039$ and $F_{e\mu}(OS) = 0.217 \pm 0.022$.

From the observed 1710 opposite-sign and 861 like-sign $e\mu$ events, equation 4 and the above results we obtain:

$$\bar{\chi} = 0.118 \pm 0.008 \pm 0.020$$

where the main systematics come from the f_s and $F_{e\mu}$ determinations. The measured value of $\bar{\chi}$ gives a constraint on the $\chi_d - \chi_s$ plane shown in Fig. 7, where a rather standard assumption has been made for the B_d and B_s fractions. Overlaid are the ARGUS (13) and CLEO (14) results and the region allowed by the Standard Model.

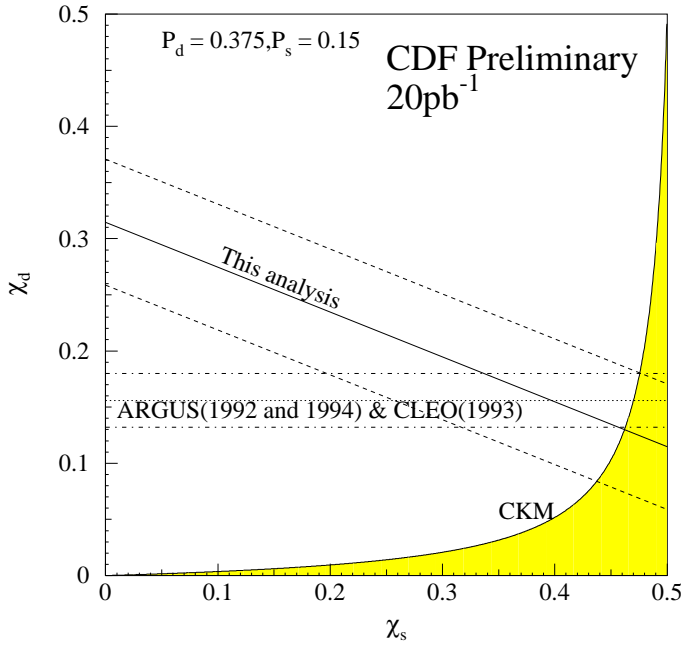


FIG. 7. The mixing parameter for B_d versus that for B_s . The bands represent 1σ uncertainty

In the $\mu\mu$ analysis we use a similar technique to measure $\bar{\chi}$, however the $b\bar{b}$ fraction in the like-sign and opposite-sign samples is directly extracted from fits to the impact parameter distribution of the muons. The $b\bar{b}$ fractions obtained this way are: 0.575 ± 0.050 for the like-sign and 0.478 ± 0.033 for the opposite-sign muons. This method has the advantage to be insensitive to many of the systematics of the $e\mu$ analysis, though it is currently statistics

limited because rather strong cuts have to be applied in the μ selection to limit the punchthrough background. From the observed 1442 like-sign and 3345 opposite-sign events and the measured $b\bar{b}$ fractions we obtain:

$$\bar{\chi} = 0.136 \pm 0.028 \pm 0.022$$

where the systematic error is dominated by the uncertainty on the fraction of sequential $b \rightarrow c \rightarrow l$ decays.

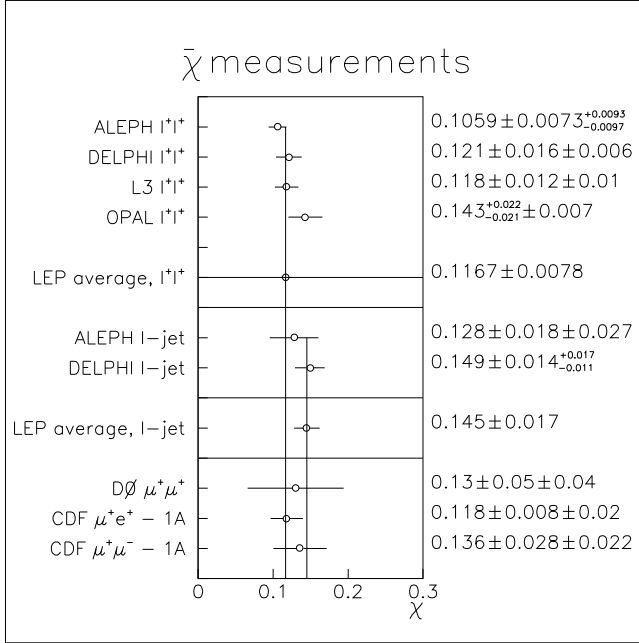


FIG. 8. Comparison of the current measurements of $\bar{\chi}$ at Fermilab and LEP

With the expected new measurements from LEP of the direct and sequential b semi-leptonic branching ratios and the additional statistics of run 1B, this analysis could provide a measurement $\bar{\chi}$ with our smallest error. In Fig. 8 we show a comparison of the CDF results with the D0 and LEP results as of March 1995.

The rather large sample of like-sign muon pairs used in the previous analysis has also been used to measure the real part of the CP violating parameter ϵ_B , which is related to the sign asymmetry through the relations:

$$A_{exp} = \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)} = D \cdot \mathcal{A}$$

where D is dilution factor which depends on f_s and $\bar{\chi}$, and

$$\mathcal{A} = F_d \chi_d \frac{\mathcal{R}e(\epsilon_d)}{1 + |\epsilon_d|^2} + F_s \chi_s \frac{\mathcal{R}e(\epsilon_s)}{1 + |\epsilon_s|^2}$$

We observe 764 $\mu^+\mu^+$ and 678 $\mu^-\mu^-$. After correcting for the measured $b\bar{b}$ fractions, we obtain:

$$\mathcal{A} = (1.6 \pm 3.8 \pm 2.0) \times 10^{-3}$$

to be compared to a Standard Model prediction $\sim 10^{-4}$. With run II luminosity we could be within reach of the Standard Model prediction for this measurement, provided the systematic uncertainty can be reduced by about an order of magnitude.

CDF time-evolution measurements

CDF uses a sample of about half a million of low p_t dimuon triggers for the measurement of Δm_d via time evolution. A substantial amount of background is removed by applying μ quality cuts and requiring the invariant mass of the dimuon system to be larger than 5 GeV/ c^2 to reject double semi-leptonic decays of the B 's. After these cuts the sample reduces to $\sim 100,000$ events. We then apply a secondary vertex b-tagging algorithm to select decays of heavy flavours and require the tag to be close to one of the muons. This is a necessary step in this analysis since we need a secondary vertex to measure the $c\tau$ of at least 1 of the B 's. We assign all tracks in the tag, excluding the associated muon, to an inclusive "D" decay and fit all these tracks to a common vertex. We then define a transverse decay length, L_{xy} , as the intersection of the "D" trajectory with that of the associated μ projected onto the transverse direction of the μ "D" system. The proper decay length cannot be calculated exactly, since in general we are missing some of the B decay particles, so, in analogy with our semi-inclusive B lifetime analysis, we define:

$$c\tau = L_{xy} \frac{M_B}{p_t^{\mu"D"}} \cdot K$$

where K is an average kinematical correction factor to be determined via Montecarlo. We also require that the p_t^{rel} of the muon relative to the "D" direction be larger than 1.3 GeV/c. This last cut reduces significantly the contribution from sequential $b \rightarrow c \rightarrow l$ decays and the direct $c\bar{c}$ background, which would otherwise significantly dilute the effect of mixing.

After all cuts we are left with 3873 events (1516 like-sign and 2357 opposite-sign). In Fig. 9 we show the dependence on $c\tau$ of the like-sign fraction, defined as: $N_{LS}(c\tau)/(N_{LS}(c\tau) + N_{OS}(c\tau))$. A clear oscillation signal is observed.

To fit the observed oscillation we need an estimate of the background, the $c\tau$ resolution function and the behaviour of the sequential decay fraction.

We find that the combined requests of 2 high quality muons and a b-tag selects an extremely pure $b\bar{b}$ sample. A 3 component fit to the μp_t^{rel} distribution in the vertex side, which takes into account direct and sequential B decays as well as direct charm production, yields a charm background in the order of 1%. A 2 component fit to the μ impact parameter in the away side,

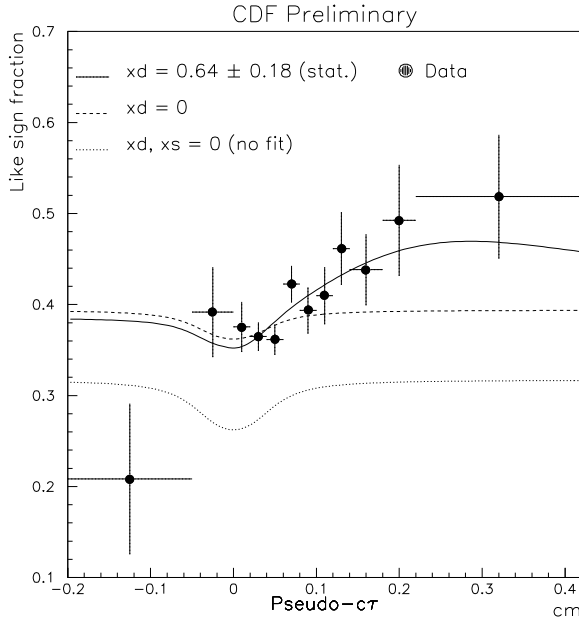


FIG. 9. Like-sign fraction versus $c\tau$. The solid line is our fit to the data; the dashed line is our fit after forcing $x_d=0$ and the dotted line is a prediction assuming just the sequential decay contribution and both x_d and $x_s = 0$

taking into account a $b\bar{b}$ and a fake muon component, estimates a fraction of fakes of $(10 \pm 3.5)\%$. Additional independent qualitative background estimates confirm these quantitative results.

We then use the Montecarlo to simulate $b\bar{b}$ events and calculate:

- the kinematical correction factor K ;
- the $c\tau$ resolution functions;
- the fraction of $b \rightarrow c \rightarrow l$ decays relative to the total number of b semi-leptonic decays, f_s . For this specific analysis we found that the b-tagging biases f_s , therefore we calculate an average fraction for the away side and one for the vertex side. Furthermore, the vertex side fraction is parametrized as a function of the measured $c\tau$ value.

Additional inputs to the fit are χ_s , which we assume saturated at 0.5, and F_d and F_s , which are the fractions of B_d and B_s contained in our sample, for these we take the values 0.37 ± 0.03 and 0.15 ± 0.04 respectively. We find that the event selection does not bias these fraction significantly.

The result of the fit to the like-sign fraction plot is:

$$\Delta m_d = 0.44 \pm 0.12 \pm 0.14 \text{ } psec^{-1}$$

TABLE 6. Expected # B 's in specific decays channels in run I and II

	Run 1A 20 pb ⁻¹	Now 60 pb ⁻¹	1A+1B 120 pb ⁻¹	Run II 2 fb ⁻¹
$B \rightarrow \psi K^\pm$	175	525 (642)	1050	17,500
$B \rightarrow \psi K^{*0}$	95	285 (284)	570	9,500
$B \rightarrow \psi K_S^0$	51	153 (138)	306	5,100
$B \rightarrow \psi \varphi$	33	99	198	3,300
$B_{u,d} \rightarrow l D_0^{(*)}$	$\sim 1,500$	$\sim 4,500$	$\sim 9,000$	$\sim 150,000$
$B \rightarrow l D_s$	76	228	456	7,600

We notice that the systematic error is largely dominated by the uncertainty on the overall fraction of sequential decays and that the statistical error is that obtained after leaving the fraction of fake background unconstrained in the fit, even if we have an independent measurement available. We expect therefore the errors to shrink considerably in the future with larger statistics and a better measurement of f_s from the LEP experiments.

FLAVOUR TAGGING AND PROSPECTS

CDF expects to collect in order of 100 pb⁻¹ of data by the end of run 1B, this adds up to a total of 120 pb⁻¹ for the whole run 1. Also we expect in the order of 1 fb⁻¹ per year after the Tevatron upgrade with the Main Injector, so it is a conservative estimate to expect that 2 fb⁻¹ will be integrated by the experiments during the run II. In Table 6 we extrapolate the number of reconstructed B mesons observed with run 1A data for various decay modes to some luminosity scenarios, assuming unchanged detector performances. Whenever new data are available they are shown in parenthesis as a check of the extrapolation. We observe that several hundred fully reconstructed B 's for each exclusive channel will be available by the end of run 1B. This will make the statistical error on the masses of B mesons negligible compared to a hard to beat systematic error in the order of 2 MeV/c². The lifetime ratio between charged and neutral B 's will reach an accuracy of 6%, while the accuracy of the B_s lifetime determination will be in the order of 0.08 psec for the $l D_s$ channel and 0.36 psec for the $\psi \varphi$ channel. A good improvement due to the increased statistics will come also for the current mixing results, with good prospects for setting a limit on Δm_s . In addition the large number of semi-inclusive B_d decays available by the end of run 1 makes them very attractive for a time-evolution mixing study which is free of many of the current systematics. However we have to find an efficient way to flavour tag these events.

The development of effective flavour tagging methods is going to be very important to improve the quality of our measurements of x_s and CP violation during run II. For analyses whose end result is obtained through an asymmetry measurement (e.g. mixing and CP asymmetries), the relevant quantity

to describe the effectiveness of the flavour tagging method used is ϵD^2 , where ϵ is the tagging efficiency and D is the "dilution". D is a measurement of the fraction of times the tagger returns a wrong answer, and is defined as: $(N_{Right} - N_{wrong}) / (N_{Right} + N_{wrong})$. As an example of how this parameter enters in the experimental errors, we show in equation 5 the formula expressing the error on the CP violation parameter $\sin(2\beta)$, when determined from the measurement of the flavour tag asymmetry in a sample of $B \rightarrow \psi K_S^0$:

$$\frac{1}{\sigma_{\sin(2\beta)}^2} = (\epsilon D^2)_{F.Tag} N_{B \rightarrow \psi K_S^0} \cdot \left(\frac{x_d}{1 + x_d^2} \right)^2 \cdot \frac{S}{S + B} \quad (5)$$

where S and B are the amount of signal and background in the $B \rightarrow \psi K_S^0$ sample and $N_{B \rightarrow \psi K_S^0}$ is the number of events in the sample. We observe that increasing the value of ϵD^2 has the same effect as increasing the size of the data sample.

In CDF we are currently studying several tagging methods: soft muons, soft electrons, jet charge and same side tagging. The soft lepton tags are already used in the current mixing analysis and exploit the feature that the sign of the lepton carries information on the type of b -quark they come from. The jet charge is defined as a momentum weighed average of the charges of the tracks contained in a jet. Due to leading effects, the jet charge is correlated with the sign of the quark which originated the jet. This technique has been used extensively and succesfully in LEP mixing analysis. Recent results from LEP (15,16) indicate that a large fraction, ~ 20 -30%, of B mesons are produced via an intermediate B^{**} state decaying into a B and a π . The sign of a π close in phase space to the B could therefore provide a flavour tag. This technique could work even without going through a resonance due to leading effects in the jet fragmentation.

For the soft muon and jet charge tagging CDF has determined directly from the data the value of ϵD^2 , obtaining the following results:

- Soft μ : $\epsilon D^2 = 0.010 \pm 0.003 \pm 0.002$
- Jet charge: $\epsilon D^2 = 0.0096^{+0.0022}_{-0.0031}$

These measurements and the extrapolations of Table 6 can be used to estimate the CP reach of CDF for the measurement of $\sin(2\beta)$.

In Fig. 10 we show the expected resolution on $\sin(2\beta)$ as a function of the number of observed $B \rightarrow \psi K_S^0$. The upper curve assumes that only jet charge and soft μ tagging are used. The bottom curve assumes a factor 4 improvement in ϵD^2 through the use of additional flavour tagging techniques. We also consider 3 scenarios for the number of observed events, marked with letters below the plot axis:

- A** is a straight extrapolation to 2 fb^{-1} from our current data, without any improvement to the CDF detector;
- B** assumes a factor 4 improvement in detector acceptance. Given the tracking and trigger upgrades which CDF plans to implement in run II (17) this should be a conservative estimate;

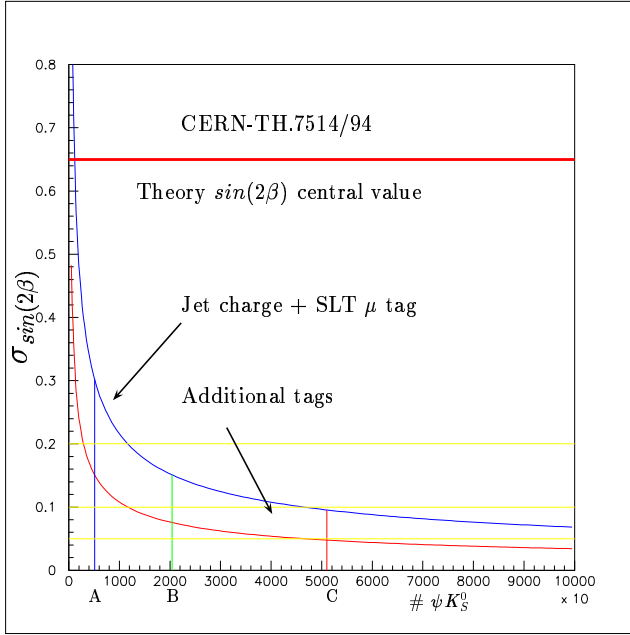


FIG. 10. Estimate of CDF $\sin(2\beta)$ resolution for several luminosity and flavour tagging scenarios

C as in case **B**, but with 5 fb^{-1} of integrated luminosity.

All in all a $\sin(2\beta)$ resolution of 0.1 or better should be quite straightforward to achieve with 2 fb^{-1} of data and the planned detector upgrades in place.

CONCLUSIONS

CDF is active in practically all areas of B physics and has already very competitive measurements for B meson masses, lifetimes and rare decays. Mixing results are still dominated by systematics, but the situation is rapidly changing thanks to new results from e^+e^- experiments and the development of additional flavour tagging techniques. We expect significant improvements with the full run 1 statistics. For the future Tevatron run measurements of CP violation and x_s should be well within reach.

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